AFRL-VA-WP-TM-2004-3001

MAGNETO-AERODYNAMIC HYPERSONICS

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DECEMBER 2003

Final Report for 03 January 1999 – 30 September 2003

STINFO FINAL REPORT

AIR VEHICLES DIRECTORATE
AIR FORCE MATERIEL COMMAND
AIR FORCE RESEARCH LABORATORY
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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
December 2003	Final	01/03/1999 – 09/30/2003

4. TITLE AND SUBTITLE
MAGNETO-AERODYNAMIC HYPERSONICS

5a. CONTRACT NUMBER
In-house

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
61102F

6. AUTHOR(S)
F. Witzeman

5d. PROJECT NUMBER
2307

5e. TASK NUMBER
N6

5f. WORK UNIT NUMBER
19

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Aerospace Vehicles Integration and Demonstration Branch (AFRL/VAAI)
Aeronautical Sciences Division
Air Vehicles Directorate
Air Force Research Laboratory, Air Force Materiel Command
Wright-Patterson Air Force Base, OH 45433-7542

8. PERFORMING ORGANIZATION REPORT NUMBER
AFRL-VA-WP-TM-2004-3001

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Air Vehicles Directorate
Air Force Research Laboratory
Air Force Materiel Command
Wright-Patterson Air Force Base, OH 45433-7542

AFOSR

10. SPONSORING/MONITORING AGENCY ACRONYM(S)
AFRL/VAAI

11. SPONSORING/MONITORING AGENCY REPORT NUMBER(S)
AFRL-VA-WP-TM-2004-3001

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Favorable interactions of electromagnetic fields and weakly ionized air for flow control have been recognized since the late 1950s. Potential applications of flow control to hypersonic flight vehicles were recently demonstrated by Russian research and concepts. The scientific knowledge base of this interdisciplinary area (i.e., fluid dynamics, electromagnetics, and chemical and thermal nonequilibrium gas dynamics) is extremely sparse. Therefore, controversy and even misunderstandings are abundant in the research community. This report documents the in-house research project that was initiated to develop a validated magneto-aerodynamic hypersonic analysis capability. The project combined experimental and computational simulations of high-speed gas dynamics in order to verify the scientific findings and define the usable scope for practical hypersonic flight. Sponsorship was provided by the U.S. Air Force Research Laboratory's Office of Scientific Research (AFOSR) as part of an Entrepreneurial Research Initiative over the period 3 January 1999 through 30 September 2003.

15. SUBJECT TERMS
Hypersonics, Electromagnetics, Ionization, Flow Control, Gas Dynamics, Fluid Dynamics

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT:**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** (Monitor)
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			F. Witzeman
Unclassified	Unclassified	Unclassified	SAR	12	**19b. TELEPHONE NUMBER** *(Include Area Code)* (937) 656-6307

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18

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1. BACKGROUND

Favorable interactions of electromagnetic fields and weakly ionized air for flow control have been recognized since the late 1950's. Potential applications of flow control to hypersonic flight vehicles were recently demonstrated by Russian research and concepts. The scientific knowledge base of this interdisciplinary area (i.e. fluid dynamics, electromagnetics, chemical and thermal non-equilibrium gas dynamics) is extremely sparse. Therefore, controversy and even misunderstandings are abundant in the research community. As evidenced in the most recent research, however, the shock wave bifurcation effect in plasma fields is identified as the mechanism for substantial wave drag reduction. This dynamic physical phenomenon thus holds the key in revolutionizing hypersonic vehicle technologies.

This in-house research project was initiated to develop a validated magneto-aerodynamic hypersonic analysis capability. The project combined experimental and computational simulations of high-speed gas dynamics in order to verify the scientific findings and define the usable scope for practical hypersonic flight. Sponsorship was provided by the U.S. Air Force Research Laboratory's Office of Scientific Research (AFOSR) as part of an Entrepreneurial Research Initiative over the period 3 January 1999 through 30 September 2003. Funding for this in-house research activity ended in fiscal year 2002, and limited effort was accomplished in 2003.

2. APPROACH

A primary objective of the research effort was to accelerate development of a computational simulation capability for magneto-aerodynamic analyses. Verification and validation of this capability were to be performed by correlations of computational results with experimental data obtained in path-finding ground tests. By combining the interdisciplinary expertise areas of plasma dynamics, microwave devices, chemical kinetics and aerodynamics, a unique experimental facility was established from an existing high-Reynolds number hypersonic wind tunnel at Wright-Patterson Air Force Base (WPAFB). The synergistic computational/experimental effort was expected to characterize key transport properties of plasma flows, as well as define the electromagnetic field ahead of strong shock waves and the resultant change in the wave drag on the aerodynamic body immersed in the hypersonic flow.

Overall, the project consisted of the following four phases:

1. Upgrades or modifications were made to the experimental facility, including the high-pressure compressed air supply and test section chamber. A force balance and double-pass Schlieren system were obtained to provide the required data.

2. A plasma generation device was provided by the Air Force Research Laboratory's Directed Energy Directorate (AFRL/DE), and diagnostic instruments were provided by the Propulsion Directorate (AFRL/PR). These components were then integrated

into the wind-tunnel data acquisition system. A complete "shakedown" of the entire facility was conducted. Preliminary data of hypersonic flow field structures, electric and magnetic field intensities, and some transport properties of the plasma fields were collected.

3. The phenomena of charge separation within the shock layer and the transient behavior of energy re-deposition downstream of the shock wave were to be examined. In both cases, the thermodynamic and electromagnetic states across the shock wave were to be recorded. The resulting aerodynamic drag force on the blunt-body test article and the energy required for the plasma generation were to be tabulated for engineering feasibility assessments.

4. A computational simulation capability was developed. The experimental data were to be used to validate the equations used, assumptions made and algorithms developed in the computer code.

The entire experimental portion was expected to be accomplished in three years. Development of the computational capability proceeded in parallel to the experiments.

3. RESULTS

The existing experimental facility at WPAFB operates at a nominal Mach number of 6. After restoration of this facility and incorporation of the aforementioned upgrades, a series of tests were performed that yielded preliminary data on aerodynamic drag and shock bifurcation for a jet spike. Plasmas were generated with a promising RF radiation technique that provided a fairly uniform field around the signal-carrying electrode. A technique for measuring the temperature of weakly ionized air was accomplished using rotational spectra of vibronic excitation of Nitrogen. Details of the research results can be found in the references listed in the Appendix.

APPENDIX

List of Publications

1. Shang, J.S., Ganguly, B., Umstattd, R., Hayes, J., Arman, M., Bletzinger, P., "Developing a Facility for Magneto-Aerodynamic Experiments," AIAA-2000-0447, January 2000

2. Shang, J.S., Hayes, J., Wurtzler, K., "Jet-Spike Bifurcation in High-Speed Flows," AIAA-2000-2325, June 2000

3. Shang, J.S., Ganguly, B., Umstattd, R., Hayes, J., Arman, M., Bletzinger, P., "Developing a Facility for Magnetoaerodynamic Experiments," Journal of Aircraft, Vol. 7, No. 6, Nov-Dec 2000, pp. 1065-1072

4. Shang, J.S., Hayes, J., Miller, J., Menart, J., "Blunt Body in Hypersonic Electromagnetic Flow Field," AIAA-2001-2803, June 2001

5. Menart, J., Shang, J., Hayes, J., "Development of a Langmuir Probe for Plasma Diagnostic Work in High Speed Flow," AIAA-2001-2804, June 2001